Nearshore Wave and Current Dynamics

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LONG-TERM GOAL

The long-term goal of our research is to increase the understanding of nearshore (shoreline to nominally 15 m depth) fluid dynamics and to improve our predictive modeling of waves and currents in that region.

OBJECTIVES

In general terms, our work under this project has been geared towards contributing to the understanding and modeling of the large scale [O(10^2 – 10^3m, 10^2s)] fluid motions in the nearshore. Specifically, our recent work has concentrated on answering the following questions:

1) How does the alongshore variability of the bottom topography affect the longshore currents?
2) How important is the nonlinear interaction between edge waves?
3) What are the possible mechanisms that can explain the observations of shear waves on planar beaches?

APPROACH

Our general approach is to use both field observations and theoretical/numerical models to increase our understanding of the large-scale fluid motions in the nearshore. In the work summarized below, we have primarily used theoretical models to answer the questions mentioned above. Our field program and data analysis are part of another project; the work carried out under that project is being reported separately.

WORK COMPLETED

As part of this project, we have successfully completed the following:

1) Mean currents – the effects of alongshore variation of topography: a) An evaluation of the limitations of using a simple model to evaluate these effects (Sancho et al., 1999) and b) An extension of the dispersive mixing of momentum to include these effects and to remove the assumption of steady state (Putrevu and Svendsen, 1999).

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2) Infragravity waves: a) An evaluation of how nonplanar topography affects edge-wave kinematics (dispersion relationship and spatial structure) (Putrevu and Oltman-Shay, 1998) and b) A general formulation of the equations governing the nonlinear interactions of edge waves (Kirby et al., 1998).
3) Shear waves: a) An evaluation of the effects of forcing on shear wave generation (Haller et al., 1998, 1999) and b) An evaluation of how lateral mixing changes the stability of longshore currents (Putrevu et al., 1998).

RESULTS

Mean currents We extended momentum dispersion results of Svendsen and Putrevu (1994) to the general case in which the assumptions of alongshore uniformity and steady state are abandoned (Putrevu and Svendsen, 1999, Three-dimensional dispersion of momentum in wave-induced nearshore currents, *European Journal of Mechanics*, 18, 409-427). We showed that, as in the longshore-uniform case, the vertical variation of the wave-induced currents enhances the lateral mixing for the depth-averaged currents by an order of magnitude. This work showed that it is possible to account for the dispersive-mixing effects of the vertical nonuniformity of the short-wave-averaged velocity field over an arbitrary bottom topography without resorting to a fully three-dimensional calculation.

We also continued our investigation of the importance of alongshore nonuniformity on the mean current patterns. In our last ONR-project, we found that alongshore inhomogenieties of the bottom topography induce alongshore pressure gradients which can significantly influence the longshore currents (Putrevu et al., 1995). For the case in which the alongshore variations of the bottom topography are weak, Putrevu et al. suggested that the alongshore pressure gradient can be calculated in a simple way. As part of the present project, we investigated the limitations of the model of the simple model proposed by Putrevu et al. The results were more or less as expected. They showed that the Putrevu et al. model works in cases in which the alongshore variations in the bottom topography vary over lengths that are long in comparison with the surf zone width. It breaks down for cases in which the alongshore variation of the topography occurs over relatively short distances (like, e.g., in a rip-channel) even if the absolute magnitude of the changes is relatively small. (Sancho, Svendsen, and Putrevu, 1999, Modeling of longshore currents over longshore nonuniform topographies: Effects of second-order terms, under review, *J. Geophys Res.*).

Infragravity waves We derived the general equations that govern the interaction of edge and shear waves on longshore-uniform beaches (Kirby, Putrevu, and Özkan-Haller, 1998, Evolution equations for edge waves and shear waves on longshore uniform beaches, *Intl. Conf. Coastal Engrg*., 203-216.) . We showed that edge waves on open coastal beaches satisfy a complex array of triad resonance conditions, thereby providing a pathway for energy to move across a range of frequencies and mode numbers. Preliminary calculations on planar beaches (in the absence of longshore currents) indicate that the time scales for energy exchange between realistic edge wave modes can be as short as ten wave periods, suggesting that the mechanism is comparable in speed to the mechanisms causing edge wave growth. In addition, these calculations showed the following intriguing result: triads involving at least one opposite-going wave lead to significant transfers (see figure 1), while triads involving three waves all propagating in the same direction do not produce an interaction. We are presently investigating the reasons the for this lack of interaction and are also extending our calculations to other topographies to determine whether the lack of interaction of three edge waves all propagating in the same direction is a general result. These results will be reported at International Coastal Engineering Conference in Sydney.

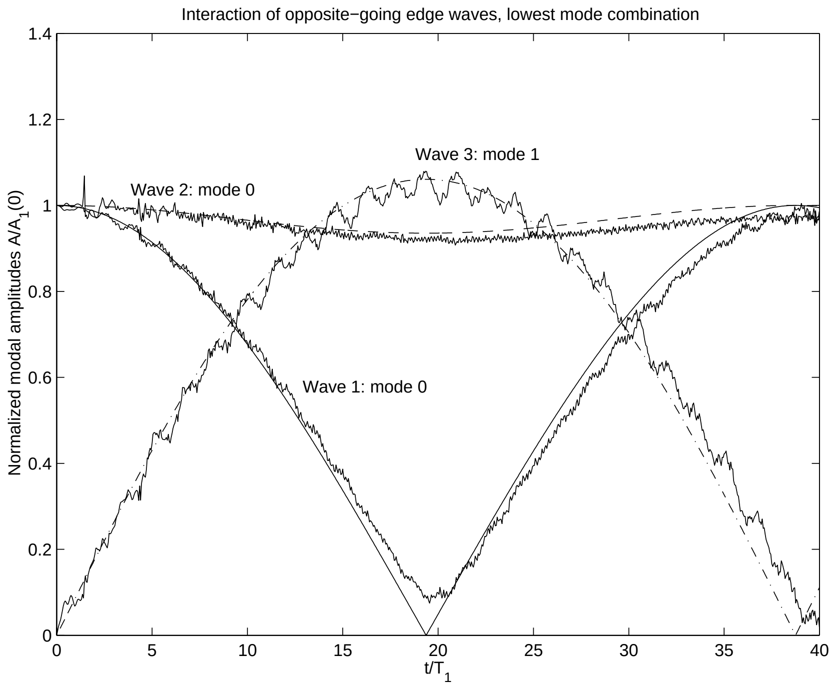

Figure 1: Triad interactions between edge waves. The triad consists of a mode 0 and a mode 1 edge wave propagating to the right (denoted by "Wave 1" and "Wave 3" in the figure) and a mode 0 edge wave propagating to the left ("Wave 2" in the figure). There is almost a complete exchange of energy between the two right going edge waves. The counter-propagating edge wave facilitates the interaction but does not play a significant role in the energy exchange. Both analytic (smooth lines) and numerical (jagged lines) results are shown here (Kirby et al., 1998).

We also investigated how nonplanar features influence the propagation of edge waves (Putrevu and Oltman-Shay, 1998, Influence functions for edge wave propagation over a nonplanar bathymetry, *Physics of Fluids*, 10, 330-332). We assumed that the bottom topography over which the infragravity waves propagate was broken down into a base profile (e.g., a planar profile) and a deviation from the base profile. The edge-wave quantities (i.e., surface elevation and wavenumber) were similarly expanded. We found that when these expansions are substituted into the edge-wave equations, the lowest order edge-wave problem reduces to the problem of edge waves propagating over the base profile (whose solution is known by assumption), and the next order problem gives us the corrections to this base solution. We found that the correction to the dispersion relationship is proportional to the (cross-shore) integral of the product of the bottom perturbation and an "influence function". This influence function has its maximum at the shoreline and decays away from the shore. Also, the magnitude of the influence function increases with edge-wave mode. These results show that the dispersion relationship is more sensitive to the features at the shoreline and quite insensitive to features at moderate distances from the shore, thus explaining the differences between Holman and Bowen's (1979) and Kirby et al.'s (1981) results. Our results also lead us to conclude that the higher modes are more sensitive to shoreline features than the lower modes. The effect of deviations from planar topography for the spatial structure similarly can be expressed in terms of influence functions, but are slightly more complicated. This work was motivated by the ONR-funded "Beach Probing System"

project and forms the basis for inverting edge-wave measurements to determine the underlying bathymetry and longshore currents.

Shear waves We investigated the effects that wave group forcing has on shear instabilities in the nearshore region (Haller, Putrevu, Oltman-Shay, and Dalrymple, 1998, Low-frequency surf zone response to wave groups, *Intl. Conf. Coastal Engrg*., 1124-1137; and 1999, Wave group forcing of low frequency surf zone motion, *J. Coastal Engrg*., 41, 121-136). This work was motivated by the results of Dodd et al. (1992) and Shrira et al. (1997). Dodd et al. found that Bowen and Holman's (1989) instability theory fails to explain the observations of shear waves on planar beaches. A related prediction is that on barred beaches there is a low-frequency, low-wavenumber cutoff below which no shear wave generation takes place. (The theory predicts that the instabilities will be damped out due to friction for realistic values of the bottom friction.) Shrira et al. showed that shear waves that are expected to be damped out by friction in the Bowen and Holman theory could grow to significant amplitudes due to triad interactions provided their initial amplitudes excceded a certain critical value. However, how such initial (small amplitude) shear waves are generated remains unexplained in the work by Shrira et al. In this work we showed that the direct forcing by wave groups sets up oscillations that are remarkably similar in all respects to shear waves. We further showed that the forced response is extremely strong and could easily provide the initial amplitudes required by the Shrira et al. model. We then analyzed field data from the NSTS and SUPERDUCK experiments and showed that there is evidence that the spatial and temporal scales of forcing required to set up these initial oscillations does exist in the field.

For essentially the same reasons mentioned above, we also investigated how the inclusion of lateral mixing changes the stability characteristics of longshore currents (Putrevu, Kirby, Oltman-Shay, and Özkan-Haller, 1998, On the viscous destabilization of longshore currents, *Intl. Conf. Coastal Engrg*., 217-229). We extended Bowen and Holman's (1989) formulation to include lateral mixing and solved the resulting equations for the model problem considered by Bowen and Holman. This solution showed that the lateral mixing significantly alters the stability characteristics of the longshore current. In particular, it eliminates the low-frequency, low-wavenumber cutoff predicted by the inviscid theory. Thus, it is plausible that lateral mixing could be an important factor in explaining the observations of shear waves in cases where the inviscid calculations predict stability (and hence no shear wave generation).

IMPACT/APPLICATION

Scientific results that will influence the modeling of nearshore waves and currents include the following:

It is important to account for alongshore nonuniformities of the bottom topography. Existing models of alongshore currents (which typically assume alongshore uniformity) easily can be extended to include minor alongshore variations as long as these variations occur over lengths that are much larger than the surf zone width.

It is possible to account for the dispersive mixing effects on the short-wave-averaged velocity field over arbitrary bottom topography without resorting to a fully three-dimensional calculation.

Either direct forcing or lateral mixing effects could potentially explain the observations of shear waves on planar beaches and could also account for the low-frequency, low-wavenumber shear waves observed on barred beaches.

The time scale of the nonlinear interactions between edge waves are comparable to the time scales over which edge waves grow due to direct forcing. Thus, any model that seeks to predict the edge wave climate in the nearshore (given the offshore wind-wave climate and the bottom bathymetry) should account for nonlinear interactions in addition to the direct forcing (due to modulations of the incident wind-waves).

RELATED PROJECTS

1) Beach Probing System (BPS), funded by ONR Coastal Dynamics. The BPS measures the offshore (of the breakers) wind and infragravity wave field to estimate the inshore bathymetry and the wave and current conditions. This application is a direct result of basic research on nearshore infragravity waves conducted by the nearshore community of scientists under ONR Coastal Dynamics sponsorship. As part of this project, we completed a large field experiment at Duck, NC in the Fall of 1998 and are presently analyzing data from that experiment. A report on this project is being submitted separately.

2) A field investigation of the dynamical importance of wind-wave groups in the surf zone, funded by NSF Physical Oceanography. We are collaborating with Prof. Ed Thornton (Naval Postgraduate School) and Prof. Ib Svendsen (University of Delaware) to analyze data collected during the 1997 SANDYDUCK experiment for evidence of vertical nonuniformity in the velocity field under infragravity waves due to forcing by wind-wave groupiness.

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